INTRODUCTION TO AGRICULTURAL AND FARMING SYSTEMS IN INDO-GANGETIC BASIN

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Indo-Gangetic basin is one of the most fertile river basins of the world and the main source of food security, rural employment and regional economic development. In fact the water-scarce but food surplus Indus basin alone meets more than 85 per cent of food demand from other basins with grain production deficits. Indo-Gangetic basin is also the cradle of Green Revolution in the South Asian region. Extensive use of production inputs (HYVs, irrigation water, fertilizers, energy and knowledge), support policies of the government and major shift to rice-wheat cropping system has raised several concerns for the long-term sustainability of irrigated agriculture in the basin. This lecture shall build upon the historical perspectives of agricultural systems, identify the major sustainability concerns, and present crop, water and land based opportunities through some interesting case studies. The lecture shall also address the specific problems of the region and present some innovative integrated systems for attaining higher productivity.

The Indogangetic basin (IGB) of India, with 20% of geographical area and 40% population contributes nearly 42% of the total food grain production in the country. The agricultural scenario is dominated by mono culture of rice-wheat rotation and 80% production comes from only 10 crops. Based upon physiography, bioc1imatic and social factors the IGB of India is divided into four sub-zones (1) Trans-Gangetic Plain (TGP), (2) Upper Gangetic Plan (UGP), (3) Middle Gangetic Plain (MGP) and Lower Gangetic Plain (LGP). The annual precipitation varies from 40 to 80 cm/year in western IGP to 175 cm/year in eastern IGP.

1. Historical Perspective of Agriculture Development in IGB

Prior to 1950, the agriculture in IGB was more of a subsistence venture. Most of the crops were grown as rainfed and very little as surplus food for marketing and trade. All kinds of crops like cotton, maize, sorghum, pearlmillet, green gram, black gram, gram, barley, mustard, lentil etc. were grown either as sole or mixed crops. Cultivation of rice was confined to mainly marshy and water logged areas of lower gangetic region. Livestock and poultry (few birds per household), vegetables, fruits were an integral part of the subsistence agriculture. Fisheries was mainly confined to fishing in common village ponds for supplementary daily diet with proteins and not for commercial purpose. Most of the agricultural operations like tillage, sowing, harvesting, thrashing were manual facilitated with the help of camels and bullocks. It was customary to maintain bullocks in excellent condition to sustain agriculture. Large public investments were made during 1950s and 1960s (23% of budget in the First Five Year Plan 1951-56) to develop hydroelectric potentials, canal irrigation and related infrastructure. About 23 per cent of 73.31 billion cubic metre (BCM) average annual flow of Indus and 11 per cent of 525.02 BCM average annual flow of Ganga basin is retained in the live storage. Upper catchments were treated since 1962 for conservation of soil, vegetation and biodiversity to prevent siltation of dams and water quality deterioration. Increased availability of energy, waving of tariffs, private investments and reliability or convenience of wells/tubewells irrigation exploited 78 and 33.5 per cent of

Indus and Ganga basin ground water progressively after 1970's. Irrigation resulted in major shifts in crops and cropping systems. Mono-culture of rice and wheat occupied maximum area replacing maize, pearlmillet, cotton, gram, mustard, barley and other pulses and oilseed crops. Green revolution was realized, poverty reduced and human development index improved but at a huge cost of fresh groundwater over exploitation and attendant second or third generation problems in many regions by 2005.

2. Indigenous Technical Knowledge for Crop Production with Particular Reference to Water Management

Before 1950 the major part of Indian and Pakistan part of IGB was rain dependent and mostly single crop in an year was grown during the rainy season. In most cases fresh ground water was available within 10 m depth. The Persian wheel technology for drawing water from the dug-out wells was quite common to meet domestic and irrigation requirement. Each village used to have 2-3 dug out community ponds for storing rain water. The stored water in these ponds was used throughout the year to meet livestock and human needs including washing. Drinking requirement was mainly met from 2-3 community dug out wells in each village from where women folk used to extract water through roped buckets particularly during early morning and evening hours. Each house hold use to store water in number of earthen pots depending upon family size. Part of the area was irrigated through the canal system. The irrigation water was mainly used for fodder crops, vegetables, maize, cotton, wheat and sugarcane.

3. Agro-Climatic Sub-Zone Wise Distribution of Major Crops/Cropping Systems in IGP and Yield Gap Analysis

Agroclimatic zonewise list of dominant cropping systems, prevailing yield levels, yield gap and constraints to production are listed in Table 1. Cropping intensity in IGP varies from 146% in MGP to 186% in TGP (average 163.5%). Irrigation is 44% by tubewells, 16.5% by canals and 39% both by tubewells and canals. Adoption of farm mechanization, input use, technical knowhow and productivity is in the order TGP>UGP>MGP>LGP. The yield gap between frontline demonstrations and farmers average varies from 54% in TGP to 100% in LGP (Table 1). There seems ample potential to venture into multi-enterprize agriculture to enhance productivity, employment and sustainability. Prevailing and potential farming systems are suggested in Table 2.

4. Current Concerns of Natural Resources Management in IGB

Climate potential of 16-18 t/ha/annum for Indo-gangetic plains have been modeled. This potential has to be realized by judicious deployment of natural resources. So far about 10 tonnes/ha/annum has been achieved and there is long way to go. Even at 10 tonnes/ha/annum productivity level, growth rate of factor productivity is quite alarming. This calls upon refinement of cost effective technologies and proper management of resource base and inputs.

4.1 Water Use Efficiency

Water use efficiency in canal and tubewell irrigation systems hardly exceeds 45% and 70%, respectively. The use of precision irrigation systems like drip and sprinkler which have much higher efficiencies is limited in IGB. Large scale pumping of ground water to meet irrigation requirement of predominant rice-wheat system has resulted in depletion of ground water. The problem of ground water depletion is serious in sizeable part of IGB. For example, between the period from 1989 to 1995, the number of blocks having dark and over-exploited ground water increased from 33 to 47% in Haryana. In states like Punjab, the ground water level is decreasing @ 30 to 50 cm/year in about 70% of the area. This increases pumping cost as in many situations the farmers are compelled to replace their centrifugal pumps with submersible pumps. Substitution of a centrifugal tube well by submersible involves additional expenditure of Rs. 50,000/or more.

The options available to balance falling ground water level include: recharging of the ground water through conservation of precious rainwater during monsoon season; diversification from high water demanding crops like rice to those which consume less water per unit dry matter production; increasing efficiency of water' use following precision irrigation schedules; matching the critical growth stage concept and agronomic manipulations such as adopting to zero tillage, bed-furrow and micro-irrigation practices.

Experiments conducted on ground water recharge in Kandi area of Punjab and Madhaya Ganga Canal area in UP clearly indicate that ground water recharge is possible provided proper soil and water conservation measures are adopted. In Kandi area it has been achieved through (1) forest rehabilitation in 45,000 ha in upper catchments, (ii) construction of 19 water harvesting dams and 7 medium capacity irrigation dams and, (iii) on-farm development. The results obtained by Khepar and his team show that all these practices resulted in revising the water balance from (-) 97, 867 ha-m to (+) 52,075 ha-m during 1979-98. Thus reversing the fall to rise in water table. Similarly, in UP Madhaya Ganga Canal (234 m^3/sec.) was constructed to divert surplus monsoonal flow for development of irrigation in dry pockets. Seepage losses from 115 - km long unlined canal (Lakhooti Branch System, 193000 ha) and from paddy fields (49,500 ha) recharged the rapidly declining aquifers from 11m bgl (meter below ground level) to 6-5 m bgl. This stored water could then be used to irrigate a sound crop during *rabi* season. Without this canal water input, the water table would have dropped to an average depth of 18.4 m by 1999 from 11 m with very high cost of pumping.

Adoption of micro-irrigation practices such as drip and sprinkler as replacement for traditional flooding and furrow irrigation methods have the potential to yield higher with almost less than half the water used. The comparison of different methods of irrigation on cotton is given in Table 3. It clearly indicates that cotton yield of 1890 kg/ha can be obtained with 81 cm of water in drip system compared to 1257 kg/ha with 203 cm of water in flood method of irrigation. Similarly, the yield per unit water applied was almost double in sprinkler and four times in drip irrigation compared to flooding method of irrigation. There is an urgent need to promote the use of micro-irrigation practices in declining ground water areas of IGB.

4.2 Soil Quality

The soil is the second important natural resource which has been over-exploited in IGB. The soil related issues of current concern are : increased pace of degradation due to physical, chemical and biological processes; decreasing fertility (particularly SOM) and deteriorating quality; heavy metal accumulation and nutrient imbalance; low efficiency of applied nutrients and specific micro nutrient deficiencies. Increased ratio of N:P:K has resulted in nutrient imbalance in general and appearance of deficiency of micronutrients. The observations recorded by Department of Soils, PAU, Ludhiana on dynamics of micronutrients in four districts of the state over a period of nearly 20 years are quite interesting and challenging (Table 4). For example, in Ludhiana district in 1970 out of 1730 samples, there were 56 samples deficient in Zn and 2 in Mn. However, when the sampling was repeated in 1998, out of 200 samples, 6 were deficient in Zn, 23 in Mn and 2 in iron. This indicates that Zn deficiency disappeared at the most sampling sites due to application of Zn by the farmers during 1970 to 1998.

Not only the application of nutrients is for short than removal by crops, but current status of nutrient use efficiency is also low. As reported by Takkar and his associates in 1997, the use efficiency of N, P, K, S and Zn is 30-50, 10-20, <80, 8-12 and 2-5%, respectively. The use efficiency of other micronutrients such as Fe, Cu and Mn varies between 1 to 2 percent. There seems wide potential to upgrade efficiency of these nutrients through better agronomic manipulations.

Practical options to upgrade the efficiency of applied fertilizer nutrients in IGB include (i) judicious combination of organic and inorganic sources and (ii) promoting large scale use of bio-fertilizers. It has been investigated that N, P and K efficiency can be markedly improved by combined application of the three sources in the right proportions. The use efficiency further improves when FYM is also added along with NPK application (Table 5). The 25 years data in Table 5 shows that application of FYM along with 100% NPK in maize has increased N, P and K use efficiency by 13.2, 10.8 and 16%, respectively.

The nutrient use efficiency can also be increased significantly by splitting the application, placement, coating N fertilizers with slow release materials and even adjusting the timing and mode of fertilizer application. Some of the measures to increase nutrient use efficiency and their relative contribution are listed in Table 6. Further, application of bio-fertilizers as alone and or in combination with other inorganic sources improves the yield and economize particularly on N due to inoculation. In legumes 15-30 % increase in yield and saving of 30-40 kg N/ha is possible through the application of bio fertilizers.

4.3 Weather Aberrations/Change and Agriculture

Frequency of weather related abberasions has significantly increased in the recent past. India experienced one of the severest droughts of the last century during 2002 that lowered food grain production nearly by 29 million tonnes. The cold wave of 2002-2003 (Fig. 1) caused significant damage to mango, litchi, papaya in Jammu and Hoshiarpur (Punjab) region (Table 7); to wheat, mustard, chillies, brinjal and tomato around Agra; to winter maize in Bihar and *boro* rice in Assam. Reduction in milk production of animals and mortality in fish ponds was also reported in northern states. The heat wave of March, 2004 (Fig. 2) in Punjab, Haryana, UP and Bihar coincided with the reproductive phase of wheat, slowed down the translocation of photosynthetic assimilates from vegetative parts to grains and a loss of 4.6 million tonnes in production was modelled. Further, during March, 2004, the maximum temperatures in Himalayas remained 6 to 10^{o}C above normal, which was a rare phenomenon. Continuation of such trends is expected to melt ice/glaciers, re-distribute water flow in rivers, raise sea level, submerge coastal habitats, islands and dislocate human and livestock settlements. The recent cold wave of 2005-2006 caused extensive damage to tomato, potato, winter maize, brinjal, peas in IGP. Predicted spatial redistribution of precipitation, droughts, floods and water balance will change land use, pests, diseases and other ecological parameters.

Adaptations to climate change calls upon pro-active or anticipatory research on crops, varieties and farming systems insensitive to cold, heat, disease, pests and moisture stresses. The concerns of rising temperature and decreasing ozone protection also demands minimizing/moderating the emission of green house gasses. Agronomic manipulations such as improved fertilizer use to reduce N_2O losses, irrigation management of rice for minimum methane production and resource conserving technologies are important for realizing desired results. Development of water harvesting and conservation techniques as adoptation to rainfall variability; CO_2 sequestration, substitution of fossil fuels with bio-fuels, weather based forewarning of incidence of pests and diseases are another important agendas of R&D.

4.4 Biodiversity

Wide variety of ecological habitants in IGB support an enormous diversity of flora and fauna. For the shake of sustainable survival of mankind, conservation of diversity is of paramount importance. A survey conducted in the Himalayan region in the altitudinal range between 1800 and 3599 m, showed that the area under traditional species has declined from 85% in 1970 to 55% in 1990. The factors responsible for erosion of biodiversity identified are: mono cropped agriculture, introduction of traditional crops to non-traditional areas, introduction of irrigation in desert areas, increased pace of land degradation such as erosion, salinity, acidity etc; indiscriminate use of inorganic inputs including pesticides and weedicides and deforestation etc. Conservation of bio-diversity must be focused on two principles (i) habitat diversity calls for blending of varieties and species and (ii) product diversity will promise optimum resource utilization with higher economic activity. Biodiversity conservation should be one of the major concerns of efficient resource management for sustainable production in IGB in future. Reorientation from mono-cropping to multi-enterprize agriculture will be a significant step to promote biodiversity conservation.

5. Crops/Cropping Systems Diversification Options

Continuous cultivation of rice-wheat in the IGB for now over 3 decades has resulted in fatigue of natural resources particularly the soil and water. In spite of optimum application of critical inputs the productivity of these crops is either stagnating or declining. Higher inputs use to maintain yield levels does not help rather results in problems of ground water contamination and environmental degradation. This calls for diversification towards other more remunerative cropping systems or resorting to alternate farm enterprises such as horticulture, agroforestry, animal husbandry, poultry, fish, high value medicinal and aromatic crops etc. Changing consumption and demand patterns and new trade opportunities are providing ample scope for diversification.

5.1 Cropping System Based Options

Scientists at the Project Directorate for Cropping Systems Research, Modipuram has identified alternate cropping systems for the predominant rice-wheat system. Their five years data clearly shows that sugarcane-ratoon-wheat system followed by rice-potato-sunflower followed by rice-potato-wheat are much more remunerative than rice-wheat system (Table 8). There are cropping systems such as pigeonpea-wheat which generate almost similar or even more economic returns (with almost 50% of water) than obtained from rice-wheat system.

To promote adoption of such diversified options, policy initiatives like assurance for procurement, fixing MSP, creation of post harvest and value addition opportunities for alternate system will be required.

5.2 Agroforestry Options

A sizeable area in IGB faces severe degradation due to erosion and salinization and has scope for tree plantations. Fuel wood is the main source of energy in rural areas and rural inhabitants particularly landless mainly depend upon trees to meet this requirement. Further to maintain ecological balance, it is imperative that 1/3rd of the total geographical area of a country or region/basin should be under forest cover. These issues call for developing area specific agrofrestry models not only to increase the forest cover but also as diversification and export generating venture. The main countries of IGB : Bangladesh, India, Nepal and Pakistan share common tree species.

The future strategic planning for agroforestry should cover (i) raising timber trees, fruit trees, trees plus grasses on all kinds of wasted abandoned lands in the IGB, (ii) developing economically viable agroforestry models for commercial farming. Some examples of commercialized agroforestry models being practiced in IGB are: *Populus deltoides* and *Eucalyptusss tereticornis* based system, (iii) exploiting agroforestry as carbon sequestration option and building-up organic matter in the soil, (iv) risk coverage option particularly during drought and floods, and (v) option for safe and economically viable disposal of sewage waters, industrial effluents and other heavy metal loaded waters.

The poplar based agroforestry is highly remunerative and gives higher returns/annum compared to arable cropping in the IGB. A five year old poplar plantation in riverine land of Punjab can yield about 240 t/ha timber wood of worth Rs. 480200. As an illustration, a comparison of five year old poplar plantations in different kind of land is given in Table 9. In addition to economic benefits, the tree based systems also improve soil fertility through build-up of organic matter and nutrients in the soil (Table 10). Without the introduction of tree component it is not possible to build-up appreciable amount of carbon in soils under tropical conditions. Assured Minimum Support Price (MSP), market infrastructure, processing and value addition opportunities are the pre-cursors for adoption of agroforestry on large scale in the basin.

5.3 Water Productivity Based Options (Farming System Approach) – case studies

It has now been realized that component, commodity and discipline oriented research approach has reached its limits. Any kind of future approach must be holistic involving biophysical and socio-economic settings targeting at interdisciplinary and inter-institutional synergies. This research concept will focus on integrated development of all components of farming systems. The basic idea would be to exploit growth potential of all the components with rational and efficient use of natural and other resources. The two issues of paramount importance in the past (i) lack of attention to alternative income generating options and (ii) the issue of inefficient and non-sustainable use of resources will needed to be more seriously addressed through farming system approach.

Animal husbandry, poultry, piggery, fisheries, trees on farm lands were all an integrated components of the farming systems in IGB. Even now these enterprises are combined with crop production on farm lands by" one or the other way. Mixed farming in addition to providing insurance against risk, also gives higher income compared to crop production alone. It also generates year round employment opportunities and credit security. As an example, comparison of different enterprises at the farm of a progressive farmer of Ludhiana (Punjab) is presenting in Table 11. Similarly a case study is cited from Meerut, UP (Table 12). These case studies clearly indicate the scope of increasing farmer's income through multi-enterprize agriculture.

5.4 Soio-economic and Environmental Issues

Large scale pumping of ground water has increased cost of pumping. Replacement of one centrifugal pump with submersible pump requires additional expenditure of about Rs. 50,000/-. Deep boring (upto even 400 feet) results in social conflicts as it reduces the efficiency of shallow tubewells in the vicinity of deep submersible tubewells. Large scale burning of rice and wheat residues is increasing green house gases load in the environment. Issues of declining total factor productivity, declining profit margins and eroded capacity of farmers to repay the loans are compelling them to quite farming and indulging into suicides. The recent National Sample Survey report has indicated that 40% farmers want to quite agriculture as profession.

5.5 Policy Issues

The dominant policy related issues for sustainability of agriculture in IGB include : minimum support price (MSP) for agricultural crops and commodities, free supply of power and water for agriculture, diversification, processing, marketing and value addition opportunities. For example, land leveling is a simple case to sake on water and improve productivity, yet subsidies are assigned to energy and to canal water supplies. The same applies to pricing of fertilizers and other inputs. The subsidy driver in fertilizer sector has to be used to correct the imbalanced fertilizer N:P:K use ratio and developing machines that help proper placement of these costly inputs.

6. Challenges of Rice-Wheat (R-W) Cropping Systems in IGB

6.1 Growth of Rice-Wheat in IGB

There has been a phenomenal increase in area under rice-wheat in IGB during last about four decades. At present the rice-wheat systems occupy 24 million ha of cultivated land in Asia. The area coverage is 10 mha in India, 2.2 mha in Pakistan, 0.8 mha in Banglades, 0.5 mha in Nepal, 10 mha in China and 0.5 mha in other countries. Of this, 13.5 mha area is in South Asia extending from the Indo-Gangetic plains to the Himalayan foothills. Rice wheat systems cover about 32% of the total rice area and 42% of the total wheat area in four countries: India, Pakistan, Bangladesh and Nepal. Geographically, the favourable rice-wheat environments in the IGP are located in the western part where winter environmental conditions are suited for wheat, irrigation and marketing facilities are assured. Comparatively less favourable rice-wheat production conditions are met in the eastern part where irrigation facilities are limited and a shorter growing period for wheat. Over the last 30 years, India's production growth for rice and wheat has matched population growth. This production growth rate is made up of increases in area and yield. Area growth has been maintained for rice and wheat at 0.5% and 1.2%, respectively. The area growth mainly resulted from double cropping or intensification of the cropping system. The yield growth of rice and wheat will have to increase by 2% to 2.5% per year over the next 20 years to match the anticipated growth in population and to provide sufficient grain to meet a dramatic increase in the demand for animal feed. This level of growth was maintained in the last three decades for rice (2.3%) and wheat (3.0%) through the use of improved seed, fertilizer and increased irrigation.

6.2 Productivity Gains and Economic Impacts

In general rice and wheat yields increased in whole of IGB till late eighties. However, in eastern India and Bangladesh where rice is the major crop and wheat has unfavourable growing conditions, rice-wheat system expanded during the 1970's in response to the food shortage and the availability of higher yielding wheat varieties. However, by 1980, the expansion of wheat stagnated at 5% of the area in Bangladesh and West Bengal with average yield of 2.0 to 2.5 t/ha, respectively. However, rice productivities continual to increase. On the other hand, in northwestern India and Pakistan rice yield stagnated and wheat yield increased. In other countries of the region, the yields of both rice and wheat are increasing.

6.3 Concerns for Sustainability of Rice-Wheat Systems

Several yield-reducing and yield limiting factors, together with delayed planting of wheat and transplanting of rice, energy, labour other input shortages; resistance of the weed *Phalaris minor* to Isoproturon and crop residual burning having contributed to the stagnating or declining production, productivity and sustainability of this system. The major concerns which limit the productivity of rice-wheat in IGB include : declining ground water levels, deteriorating water quality, reducing organic carbon levels, accumulation of heavy metals in soil and recycling in animal-human-environment chain and weather based abnormalities. Nutrient deficiencies of sulpher, potash, zinc, iron, manganese and boron are emerging. Widening of N:P:K ratio owing to excessive use of N fertilizers, contamination of ground waters with nitrates, arsenic, fluoride, selenium etc. are becoming emerging challenges.

6.4 Role of RCTs for Addressing the Concerns

Improving Water Use Efficiency

i. **Reduce puddling intensity:** Rice alone consumes major share of irrigation water and 50-80% of the total water applied is lost on deep percolation. The puddling operation requires two ploughings followed by one planking to reduce percolation losses.

ii. **June planting:** Farmers have resorted to early transplanting of paddy in the month of May whereas it is recommended that transplanting should be done after 10 June. The ET demand in the May transplanted rice is 80 cm as compared to less than 63 cm in June planted. Timely transplanting of paddy in June thus can help in checking the declining water table in IGB.

iii. **Irrigation schedule:** It is recommended that initially continuous ponded water is required for two weeks instead of three weeks. The later irrigations to rice should be given two days after the infiltration of ponded water. The last irrigation should be given two weeks before the harvest. This helps in saving about 15-16 cm of water without any loss in yield.

iv. **Furrow irrigation:** Irrigation application in furrows decreases water requirement of the crops and help in saving of about 2 cm of irrigation in every irrigation applied without any reduction in yield. Wide row crops like cotton, sunflower, maize should be planted on the ridges and irrigations be applied in furrows. Similarly, application of straw mulch improve the water use efficiency and helps in water saving by reducing the ET losses.

v. **Drip/micro sprinkler/sprinkler irrigation:** The recent innovations in application of irrigation water i.e. drip sprinkler irrigation systems need to be introduced in IGB since these systems are able to apply water precisely without much water loss.

- Laser land levelling improves yield of rice and wheat by 6-10% and saves water by 10-20%. Already 700 farmers adopted this technology and area coverage is about 10000 ha.

- No till farming (zero tillage) saves water by 20-30% and gives almost same or little higher yield than conventional tillage. Already this practice is followed in about 2 million ha area in IGB.

- Direct seeded rice technology can improve water productivity by 15-18% and profits by 10-15%. Deep water rice, an important rice crop in very low lying areas of Bangladesh, Eastern India and Nepal, is grown like wheat and planted onto non-puddled soils.

- Furrow irrigated raised seed planting (FIRB) can save on irrigation water by 20-30% without loss in crop yield. The advantage is more in wheat than in rice.

- The introduction of extra short duration (ESD) pigeon pea (ICPL - 88039) in place of rice during *kharif* and adopting FIRB planting system helps increase water productivity and economic returns.

- Maize has good potential to substitute for rice and wheat both during *kharif* and *rabi*.

- Short duration vegetables and flower crops like gladiolus, chrysanthemum and marigold can be cultivated with maize during Rabi under FIRB system. Dual purchase (grain+fodder) maize (Variety J 1006) during winter season is highly productive and profitable crop as diversification option. This variety has the potential to meet green fodder requirement during April-May which otherwise is considered lean period.

- Leaf colour chart (LCC), SPAD and Green Seeker technology for matching fertilizer application with crop requirement is providing dividends in terms of economic gains and to halt excessive use of fertilizers.

- No tillage direct seedling of pigeonpea, clusterbean and soybean reduces cultivation cost significantly.

- To economize on water use, improved soil quality and to reduce cost of cultivation there seems strong case to replace rice-wheat at least in 10% area of IGB with low water demanding crops. The promising alternate crops are listed in Table 13.

Weeds compete with crops for water, nutrients, light and space and thus cause appreciable loss in yield. Chemical weed control technology has been developed and standardized for most crops under varying agro-ecological conditions. There has been steady increase in the consumption of weedicides. However, continuous use of herbicides particularly of the same group has resulted in development of resistance in weeds. The notable example is of *Phalaris minor* which has developed resistance to the most effective and commonly used herbicide Isoproturon. The other issue is of herbicide residue in soil-plant-human chain. Recently, it has been reported that crops like sorghum, maize and pearlmillet did not germinate in the fields where Leader weedicide was used in the previous crop. These are alarming observations and require reorientation of our research efforts from chemical based control measures to integrated/biological weed management strategies. Biological weed control has proved quite useful for managing weeds in field crops and wastelands but more rigorous efforts are required to standardize and promote biological weed control.

7. Crop Production Strategy under Special Situations

7.1 Marginal Ground Water Quality

Studies on groundwater resources indicate that 25 to 84% of the poor quality waters are used for irrigation particularly in arid and semi-arid regions (Table 14). For example UP and Haryana have 47 and 62% of the ground waters as brackish or/and saline. A sizeable area in Pakistan and Bangladesh also experiences the problem of ground water quality. Based upon climate, soil, water and crop factors the Central Soil Salinity Research Institute, Karnal has standardized water quality guidelines for successful use of poor quality waters for agricultural production. These guidelines may be kept in mind while irrigating the crops using poor quality waters. It has also been investigated that detrimental effect of such waters can be moderated through mixing or alternate use of limited good quality water. Data in Table 15 on 6 years average yield of rice and wheat show that almost similar yields of these crops as obtained with canal water can be achieved through the alternate and mix use of sodic and canal water.

7.2 Sodic Soils

A sizeable part of IGB has higher concentration of salts particularly sodium in the root zone. The problem is more serious in India and Pakistan. A sizeable area has been reclaimed using gypsum based technology for growing rice and wheat. India, Bangladesh and Pakistan also have sizeable area affected by coastal salinity due to ingression of sea water.

7.3 Saline Waterlogged Soils

The rising trend of water table in irrigation commands is another serious concern. Depending upon situations, the water table is rising @ 0.29 m to 1.20 m per annum (Table 16) in major canal commands due to inefficient water conveyance system. In many situations, rise in water table is also associated with development of salinity and thus making otherwise productive lands unsuitable for crop production. The strategies for balancing this hydrological imbalance should involve: (i) lining of the water conveyance system, (ii) planting of trees, grasses having high transpiration capacity alongside the water courses to trap seepage. The trees like *Eucalyptus, Populus* and *Casuarina* act as biopumps to consume seepage flow, (iii) inclusion of trees such as *Eucalyptus* and *Populus* as a component of cropping in all areas having rising water table trends and (iv) installation of effective drainage system for release of excess water. It has been proved that by lining of all the components of canals irrigation system, 66% increase in canal water supply could be achieved. The contribution of lining canal system components is : main canal 15%, distributaries 8%, channels 28% and field channels 15%.

8. Multiple Use of Water for Multi-enterprize Agriculture

One of the options to increase water productivity is its multiple use and recycling in crops, fisheries, livestock, horticulture, agroforestry and dairying in a unified farming system approach. Integration of fish with crops has the potential to increase productivity by 3 to 6 times. Recycling of nutrient rich fish pond water in crops improves the soil quality and saves on chemical inputs. In-situ composting of crop residues and farm water supplies nutrients in the form of compost/FYM which can be directly used as manure to crops and feed for the fish. Few case studies of multi-enterprize agricultural systems aimed at improving water productivity soil quality, residue recycling, economics and employment generation will be discussed.

9. Future Research and Policy Issues

- Promotion of resource conservation technologies and favourable policy for their large scale adoption
- Promotion of conservation agriculture with major focus on crop rotations involving low water requiring crops, no tillage practices and retaining crop residue on the soil surface
- Multiple use of water in multi-enterprize agriculture to improve water productivity
- Participatory water management farming system research
- Policies that will promote diversification into pulses, oilseeds, medicinal and biodiesel crops in IGB. Addressing the issues of processing, value addition, marketing and trade
- Environmental issues related to burning of crop residues and intensive use of inputs, contamination of groundwater
- The present subsidized input supply policy needs review and public investments may be allocated for resource conservation activities in place of only direct production subsidies.

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Table 1. Agro-climatic zone-wise yield in terms of rice equivalent, yield gap (%), yield advantage demonstrated on 2200 farmers fields and constraints
(Three years average from 2000-01 to 2002-03)

S. No.	Agro-climatic region	Pre-dominant cropping systems	Prevailing yield t/ha (Rice yield equivalent)	Yield gap (%)	Constraints
1.	Lower Gangetic Plain	Rice-rice	5.2	100	• Flood/water-logging • Poor quality water
2.	Middle Gangetic Plain	Rice-wheat	4.7	57	• Lack of technical know-how • Flood and drought • Weed and pest infestation • Poor manage-ment of Diara, Tal, and Char lands
3.	Upper Gangetic Plain	Rice-wheat Pearl millet-wheat	5.6 4.6	59 66	• Decline in water table • Late planting of wheat • Infestation of pest and weed
4.	Trans Gangatic Plain	Rice-wheat Pearl millet-wheat	7.5 5.6	75 54	• Decline in water table • Poor quality of ground water • Salinity and sodicity

Note: The constraints which are similar across the agro-climatic zones are lack of organized market, processing and credit facilities, non-availability of quality seeds and agro-chemicals, multiple nutrient deficiencies in intensive cropping areas, inadequate fertilizer use in rainfed, hilly and tribal areas, lack of technical know-how and non-regulated water supply in canal system.

Table 2: Farming system options in IGP

Agro-climatic region and area under major crops (000, ha)	Prevailing farming system	Potential farming system
Lower Gangetic plain region	Rice-rice/jute-rice-mustard	Crops + horticulture + dairy + ducks + fish
Middle Gangetic plain region	Rice-wheat	Crops + dairy + fishery + mushroom
Upper Gangetic plain region	Rice-wheat/Pearlmillet-wheat	Crops + dairy + fishery + bee keeping + horticulture
Trans Gangetic plain region	Rice-wheat; rice/sorghum-wheat + dairy	Fishery + piggery crop + dairy (crossbred) crops + dairy + vegetable crops + dairy + poultry crop + dairy + fishery + piggery

Table 3: Average cotton yields and water application in different methods

Particulars	Irrigation methods			
	Flooding	Furrow	Sprinkler	Drip
Lint yield, Kg/ha	1257	1350	1300	1890
Water applied, cm	203	165	106	81
Yield to water use ratio, Kg/cm	6.19	8.18	11.3	23.3

Table 4: Changes in the micronutrient status in soils of Punjab

District	Year	No. of samples	% Samples deficient			
			Zn	Cu	Fe	Mn
Ludhiana	1970	1730	56	-	-	2
	1998	200	6	0	2	23
Sangrur	1977	360	71	4	7	0
	1998	100	14	0	18	35
Jalandhar	1977	742	45	6	0	0
	1998	100	14	0	13	39
Ropar	1980	500	52	0	0	0
	1994	126	8	0	6	9

(Source: Department of Soils, PAU, Ludhiana)

Table 5: Apparent N, P and K use efficiency (%) of crops under balanced and IPNS

Crop	No. of Crops	100% N	100% NP	100% NPK	100% NPK + FYM
		N use efficiency			
Maize	25	16.2	30.6	32.0	45.2
Wheat	25	32.2	51.4	64.0	68.2
		P use efficiency			
Maize	25	10.0		17.6	28.4
Wheat	25	21.0		30.4	34.2
		K use efficiency			
Maize	25			43.0	59.0
Wheat	25			93.0	108.0

Source : Brar and Pascricha, 1998

Table 6: Measures to increase nutrient use efficiency

Measure	Nutrient	Increase in Nutrient use efficiency(%)
Split vs. single dose application	N	15-20
Furrow placement vs broadcast application	PK	20-30
The incorporation of urea super granules (USG) vs split application	N	20
The foliar vs basal application	Micro-nutrients	15-20
Neem coated vs prilled urea	N	5-10
Preferential application of phosphorus to wheat in rice-wheat sequence	P	50

Table 7: Effect of cold wave on fruit orchards in selected villages of Hoshiarpur region

Name of the farmers & village	Kind of orchard and age	Area in acres	Crop/Fruit damage (%)	Damage to plant (%)
Sh..U.S. Chatha Village Mehlawali	Litchi 12 years	8	100	30-60
Sh. J.S. Lali Bajwa Village Mehlawali	Litchi 15 years	2	100	30-60
Sh. K.S.Gill Village Kharkan	Mango 15 years	10	100	60-80
	Litchi 12 years	5	100	60-80
Sh. Ranjit Singh Villege Kantia	Mango 10 years	45	100	80-100
	Aonla 15 years	10	100	80-100
Mr. Ramji Das Village Dholwaha	Mango 8-10 years	30	100	40-60
Sh. J.S. Dhaliwasl Village Dholwaha	Mango 8-10 years	60	100	40-60
Mr. Deepal Puri Village Chohal	Mango 30 years	5	100	100

Table 8: Comparative productivity in terms of wheat equivalent yield, net returns water use and employment generation from different cropping systems (average of five years)

Cropping System	Mean yield (t/ha)	Net returns (Rs/ha)	Water requirement/ year (cm)	Employment generated (man days/year)
Rice-Wheat	8.74	26763	165	182
Rice-Berseem	9.37	18572	210	184
Rice-Potato- Wheat	16.40	39891	220	233
Rice- Potato-Sunflower	19.54	48136	205	263
Rice- Wheat-Green gram	10.61	30067	205	230
Sorghum (F)-Wheat	7.77	25300	100	96
Sorghum (F)- Toria-Wheat	8.80	24912	135	143
Pigeopea- Wheat	8.81	33194	72	102
Maize- Wheat	8.61	25770	112	104
Sugarcane-Ratoon-Wheat	14.46	53151	350	207

Table 9: Comparison of five year old poplar plantations in agroforestry system

Plantation	Productivity (5 years)		Returns*
	Timber volume (m^3)	Timber weight (t/ha)	Rs/ha/year
Absentee poor table land	47.4	37.8	15120
Resident poor table land	146.5	119.3	47720
Resident good table land	202.9	165.5	66200
Resident good riverine land	295.4	240.1	96040
Resident table land well managed	240.3	195.8	78320

Source: Dhanda, 1999; (* Calculated on the basis of sale rate of Rs. 2000/t)

Table 10: Changes in soil properties (0-30 cm) under different tree-crop combinations in 5 years

Land use system	Organic carbon (%)	Available N (Kg ha^{-1})
Crop based system	+0.07	+10
Eucalyptus based	+0.12	+21
Acacia based	+0.20	+31
Populus based	+0.17	+25

Table 11: Comparison of different enterprises at integrated farm of Sh. Darshan Singh near Ludhiana, Punjab

Enterprise	Yield (q/ha)	Rice equivalent yield (q/ha)	Gross return (Rs)
Rice-wheat	75 + 50	145.0	81200
Fish + piggery	40 + 30	275.00	154000
Crop + dairy	125 + 40	202.1	113200

Table 12: Economics of dairy based farming system in Meerut, UP

Farm size	Net return (Rs/ha)	
	Sugarcane-wheat	Sugarcane-wheat + dairy
Marginal	38750	45950
Small	39105	45825
Medium	43785	51225
Large	42430	47950

Source: Project Directorate for Cropping Systems Research, Modipuram, Uttar Pradesh

Table 13: Suggested alternate crops for rice and wheat

State	Rice	*Kharif* alternate crop	Wheat	*Rabi* alternate crop
Punjab	Rice	Maize, green gram/ black gram	Wheat	Mustard, chick pea, lentil, field peas
Haryana	Rice	Maize, green gram/ black gram	Wheat	Mustard, chick pea, lentil
Uttar Pradesh	Rice	Pigeonpea (short duration), green gram/black gram	Wheat	Mustard, chick pea, field peas, lentil,
Bihar	Rice	Not suggested as most of the rice area is waterlogged	Wheat	Maize, mustard, lentil

Table 14: Percentage of use of poor quality waters in different states

State	Percentage (estimated values)
Andhra Pradesh	32
Gujarat	30
Haryana	62
Karnataka	38
Madhya Pradesh	25
Rajasthan	84
Uttar Pradesh	47

Table 15: Management of sodic waters for irrigation of rice and wheat

Water quality	Av. Yield of 6 years, t/ha	
	Rice	Wheat
Canal water (CW)	6.8	5.4
Sodic water (SW)	4.2	3.1
2 CW-SW	6.7	5.2
CS-SW	6.3	5.1
CW-SW	5.7	4.8

Table 16: Rising trend of water-table in irrigation commands

Irrigation command	Rise of water table (m/annum)
IGNP, Rajasthan	0.29-0.88
Western Yamuna & Bhakra Canal	0.30-1.00
Sharda Sahayak, U.P	0.68

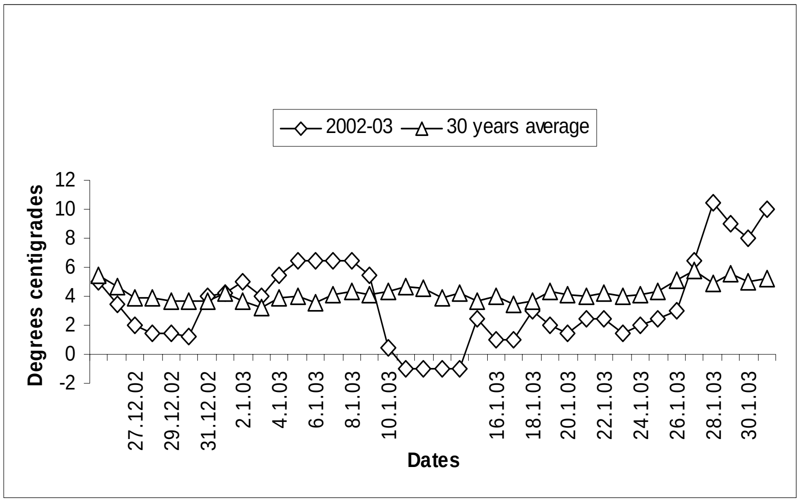

Fig. 1. Cold Wave of 2002-03 : Daily minimum temperature of 2002-03 and 30 years average at Dehradun

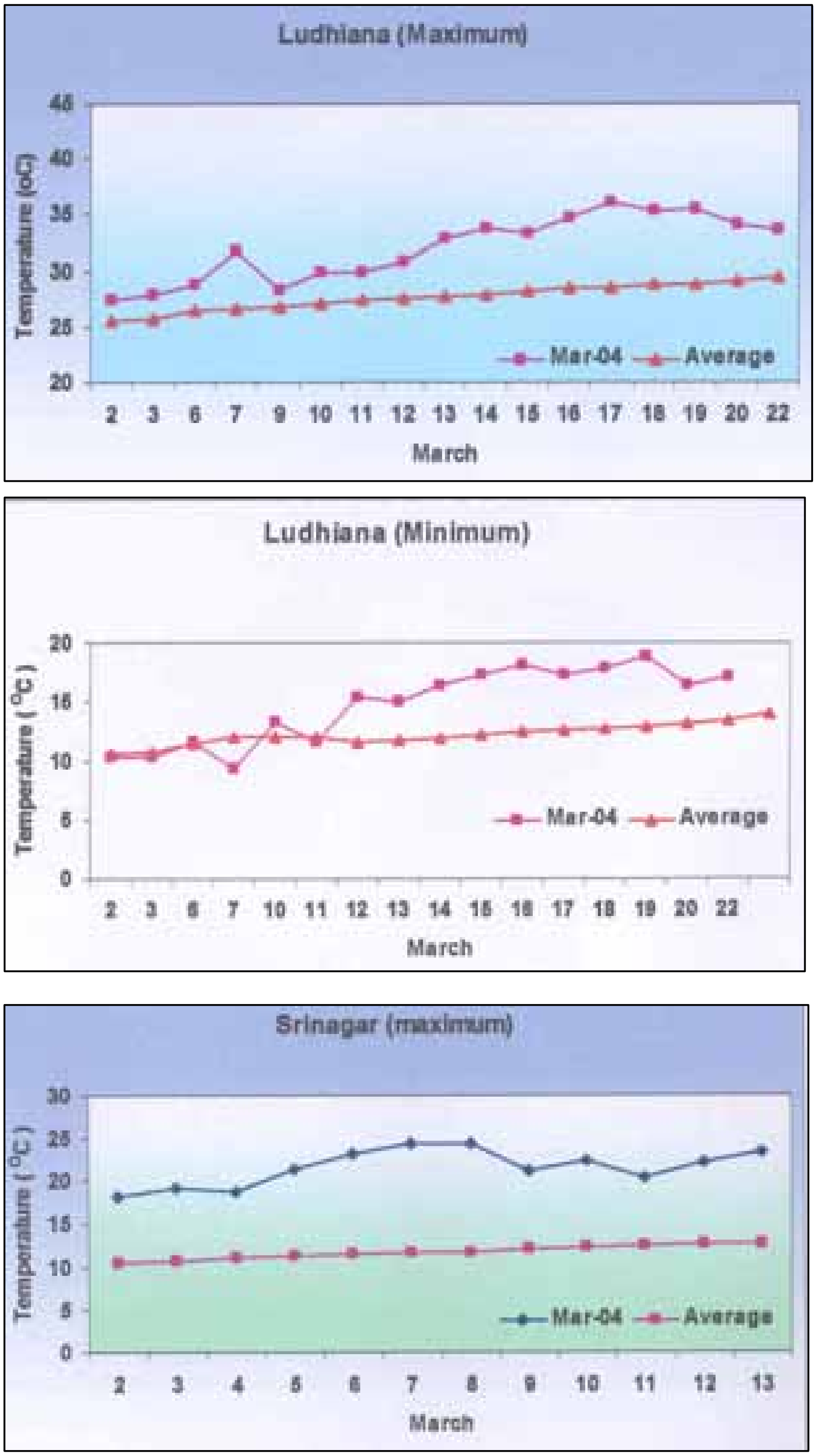

Fig. 2. Heat wave of March 2004